Zero Power Acoustic Signal Processing

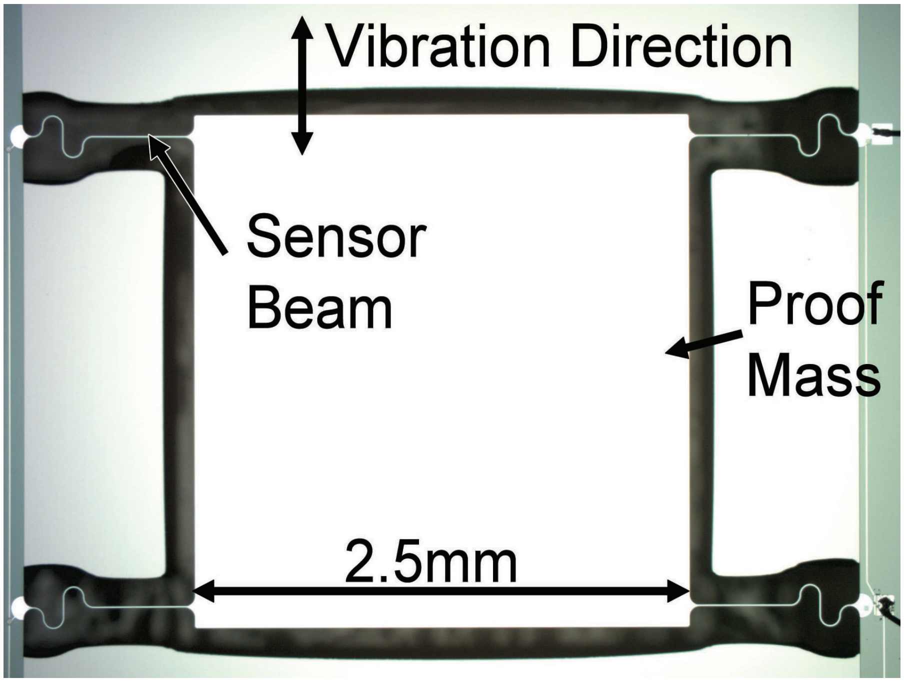

Figure 1: Photograph of zero power, 500 Hz vibration sensor. The 2.5 X 2.5 mm proof mass (coated with reflective metal) is supported at each corner by a sensor beam.

Pre-processing signals in the acoustic domain can eliminate stand-by power in certain classes of autonomous sensors

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Eliminating standby power is critical to extending the lifetime and to reducing the size of unattended sensors. Ideally, an autonomous sensor system would remain in standby consuming zero power until an event triggers power-up of the entire device for data logging, processing or transmission. In reality, however, processing the wake-up event often requires significant power consumption, particularly for complex event signatures, which limits device lifetime and size. Sandia is developing a microelectromechanical (MEMS) circuit capable of processing complex vibration signatures while consuming near zero power.

The wake-up circuit operates via piezoelectric transduction of mechanical vibration that produces an output current proportional to the mechanical displacement. When no vibration is present, there is zero displacement, zero output current and zero power consumption. Under vibration, a strain induced in a thin-film piezoelectric layer produces a current that is passed through a circuit to create a voltage that must be large enough to turn on a transistor. Since the displacement and piezoelectric output current can be engineered to respond only to certain vibration frequencies, complex vibration profiles can be programmed into the wake-up circuit and processed in the mechanical domain without consuming power. This technology is readily extendable to zero power processing of radio frequency signals as well. The major challenges being addressed are: (1) covering the frequency range of interest in a single microfabrication process, and (2) realizing a large enough voltage signal swing to trigger microsystem wake-up in an event while consuming zero power in standby.

A micromachined 500 Hz vibration sensor is shown in Figure 1. It is fabricated in a 5-mask process in Sandia's MESA (Microsystems and Engineering Sciences Applications) facility capable of producing sensors and sensor arrays operating from 100 Hz to 10 kHz. The sensor consists of a tiny 0.3 mm^3 proof mass suspended from the silicon wafer by four 1-mm-long serpentine sensor beams. The resonant vibration frequency and amplitude response of the sensor are engineered by setting the proof mass size, sensor beam length, and the size of the serpentine. In the presence of a vibration, the sensor will vibrate back and forth in the direction shown in Figure 1. If the frequency of vibration is resonant with the sensor, the magnitude of the sensor displacement will be amplified by approximately 500 times.

A cross-section of a sensor beam and zero power circuit schematic are shown

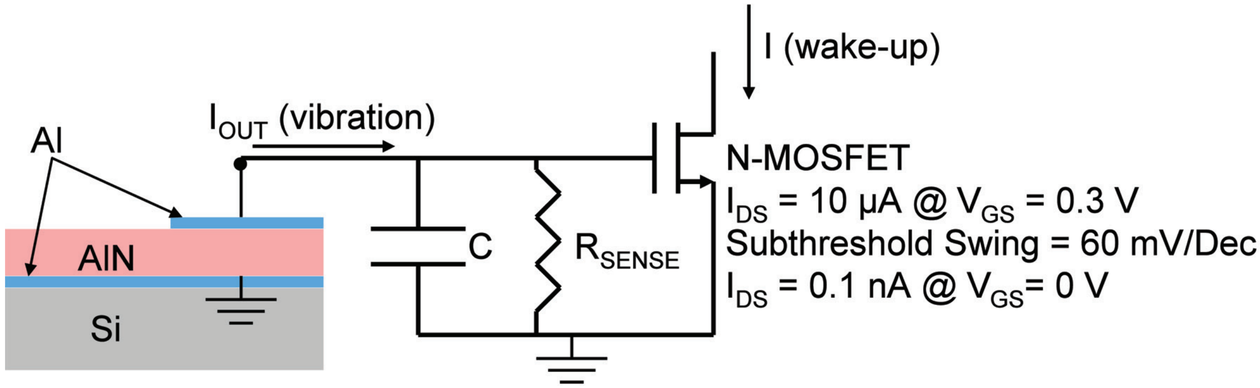

Figure 2: Sensor beam cross-section and zero power circuit schematic.

in Figure 2. Under vibration, the displaced sensor beams create strain in the thin film piezoelectric aluminum nitride (AlN) layer. The piezoelectric effect converts the strain into an output current that is proportional to both sensor displacement and vibration frequency and is subsequently converted into a voltage. The maximum voltage for a given displacement amplitude is limited by the piezoelectric constant of AlN and the parasitic capacitance of the sensor; thus high quality piezoelectric thin films are vital for achieving high output voltages.

Figure 3 shows the modeled response of the 500 Hz sensor in Figure 1 *vs*. frequency for an input vibration of 0.1 G, where 1 G is the acceleration due to gravity at sea level. The resonance of the sensor at 500 Hz is clearly seen as the output sensor voltage reaches 0.7 V for a maximum sensor displacement of only 50 µm. A typical MOSFET (metal-oxide field effect) transistor shown in Figure 2 will turn on when the input voltage exceeds the threshold (in this case 0.3 V), but will consume as little as 0.1 nA when no vibration-induced voltage is present. Based on finite element modeling, the zero power sensor system currently in development will be capable of processing vibration signals as low as 10 milliG. To date, Sandia has produced an array of four sensors operating at 500, 667, 834 and 1000 Hz that occupies a total volume of 0.5 mm^3.

Potential applications of unattended, zero power vibration sensors include the monitoring of machinery such as industrial equipment, airplanes and automobiles, where abnormal vibration profiles measured in key locations can be an early sign of failure. Other applications include circumstances where sensors must be automonously deployed for long periods without the need for maintenance such as changing batteries.

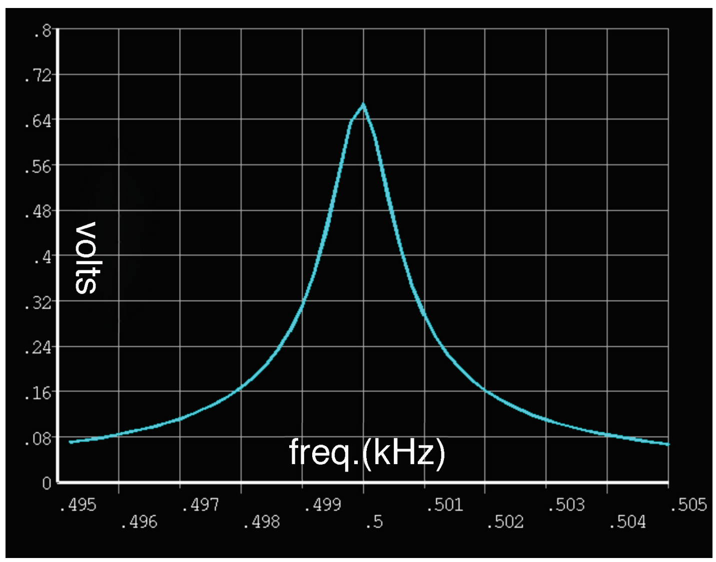

Figure 3: Finite element model predicted response of the sensor in Figure 1 under a 100 milli-G vibration *vs*. vibration frequency.

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